

New symmetries in microphysics, new stable forms of matter around us

MAXIM YU. KHLOPOV

Centre for Cosmoparticle physics "Cosmion",
Miusskaya Pl. 4, 125047 Moscow, Russia

Extension of particle symmetry implies new conserved charges and the lightest particles, possessing such charges, should be stable. Created in early Universe, stable charged heavy leptons and quarks can exist and, hidden in elusive atoms bound by Coulomb attraction, can play the role of dark matter. The problem of this scenario is that in the expanding Universe it is not possible to recombine all the charged particles into elusive "atoms", and positively charged particles, which escape such recombination, bind with electrons in atoms of anomalous isotopes with pregalactic abundance, generally exceeding terrestrial upper limits. Realistic scenarios of composite dark matter, avoiding this problem of anomalous isotope over-production, inevitably predict the existence of primordial "atoms", in which primordial helium traps all the free negatively charged heavy constituents with charge -2 . Study of the possibility for such primordial heavy α particle with compensated charge to exist as well as the search for the stable charged constituents in cosmic rays and accelerators provide crucial test for the new forms of stable matter.

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1 Introduction

Reminding Majorana's impact on the development of our understanding of microscopic structure of matter, we consider the nontrivial forms of matter, following from extension of standard model.

The problem of existence of new particles is among the most important in the modern high energy physics. This problem has important cosmological aspect, if these particles are stable. Then they should be

present in the Universe along with normal baryonic matter. Various new weakly interacting massive species, and especially, neutral Majorana fermions (like neutralino from supersymmetric models) are widely considered as candidates for the cosmological dark matter. Here we discuss an alternative approach, involving heavy charged constituents of composite dark matter.

Recently at least three elementary particle frames for heavy stable charged particles were considered: (a) A heavy quark and heavy neutral lepton (neutrino with mass above half the Z-Boson mass) of fourth generation [1, 2]; which can avoid experimental constraints [3, 4] and form composite dark matter species [5, 6, 7]; (b) A Glashow's "Sinister" heavy tera-quark U and tera-electron E , which can form a tower of tera-hadronic and tera-atomic bound states with "tera-helium atoms" ($UUUEE$) considered as dominant dark matter [8, 9]. Finally, (c) AC-leptons, predicted in the extension [10] of standard model, based on the approach of almost-commutative geometry, [11] can form evanescent AC-atoms, playing the role of dark matter [10, 12, 13].

In all these models, predicting stable charged particles, the particles escape experimental discovery, because they are hidden in elusive atoms, maintaining dark matter of the modern Universe. It offers new solution for the physical nature of the cosmological dark matter.

This approach differs from the idea of dark matter, composed of primordial bound systems of superheavy charged particles and antiparticles, proposed earlier to explain the origin of Ultra High Energy Cosmic Rays (UHECR) [14]. To survive to the present time and to be simultaneously the source of UHECR superheavy particles should satisfy a set of constraints, which in particular exclude the possibility that they possess gauge charges of the standard model.

The particles, considered here, participate in the standard model interactions and we discuss the problems, related with various dark matter scenarios with composite atom-like systems, formed by heavy electrically charged stable particles.

2 Charged components of composite dark matter

2.1 Charged tera-particles

In Glashow's "Sinister" $SU(3)_c \times SU(2) \times SU(2)' \times U(1)$ gauge model [8] three Heavy generations of tera-fermions are related with the light

fermions by CP' transformation linking light fermions to charge conjugates of their heavy partners and vice versa. CP' symmetry breaking makes tera-fermions much heavier than their light partners. Tera-fermion mass pattern is the same as for light generations, but all the masses are multiplied by the same factor $S = 10^6 S_6 \sim 10^6$. Strict conservation of $F = (B - L) - (B' - L')$ prevents mixing of charged tera-fermions with light quarks and leptons. Tera-fermions are sterile relative to $SU(2)$ electroweak interaction, and do not contribute into standard model parameters. In such realization the new heavy neutrinos (N_i) acquire large masses and their mixing with light neutrinos ν provides a "see-saw" mechanism of light neutrino Dirac mass generation. Here in a Sinister model the heavy neutrino is unstable. On the contrary in this scheme E^- is the lightest heavy fermion and it is absolutely stable.

Since the lightest quark U of Heavy generation does not mix with quarks of 3 light generation, it can decay only to Heavy generation leptons owing to GUT-type interactions, what makes it sufficiently long living. If its lifetime exceeds the age of the Universe, primordial U -quark hadrons as well as Heavy Leptons E^- should be present in the modern matter.

Glashow's "Sinister" scenario [8] took into account that very heavy quarks Q (or antiquarks \bar{Q}) can form bound states with other heavy quarks (or antiquarks) due to their Coulomb-like QCD attraction, and the binding energy of these states substantially exceeds the binding energy of QCD confinement. Then (QQq) and (QQQ) baryons can exist.

According to [8] primordial heavy quark U and heavy electron E are stable and may form a neutral most probable and stable (while being evanescent) $(UUUEE)$ "atom" with (UUU) hadron as nucleus and two E^- s as "electrons". The tera gas of such "atoms" seemed an ideal candidate for a very new and fascinating dark matter; because of their peculiar WIMP-like interaction with matter they might also rule the stages of gravitational clustering in early matter dominated epochs, creating first gravity seeds for galaxy formation.

2.2 Stable AC leptons from almost commutative geometry

The AC-model [10] appeared as realistic elementary particle model, based on the specific approach of [11] to unify general relativity, quantum mechanics and gauge symmetry.

This realization naturally embeds the Standard model, both reproducing its gauge symmetry and Higgs mechanism, but to be realistic,

it should go beyond the standard model and offer candidates for dark matter. Postulates of noncommutative geometry put severe constraints on the gauge symmetry group, excluding in this approach, which can be considered as alternative to superstring phenomenology, supersymmetric and GUT extensions. The AC-model [10] extends the fermion content of the Standard model by two heavy particles with opposite electromagnetic and Z-boson charges. Having no other gauge charges of Standard model, these particles (AC-fermions) behave as heavy stable leptons with charges $-2e$ and $+2e$, called here A and C , respectively. AC-fermions are sterile relative to $SU(2)$ electro-weak interaction, and do not contribute to the standard model parameters. The mass of AC-fermions is originated from noncommutative geometry of the internal space (thus being much less than the Planck scale) and is not related to the Higgs mechanism. The lower limit for this mass follows from absence of new charged leptons in LEP. It was assumed in [12, 13] that $m_A = m_C = m = 100S_2 \text{ GeV}$ with free parameter $S_2 \geq 1$. In the absence of AC-fermion mixing with light fermions, AC-fermions can be absolutely stable. Such absolute stability and absence of mixing with ordinary particles naturally follows from strict conservation of additional $U(1)$ gauge charge, which is called y -charge and which only AC-leptons possess [12, 13].

If AC-leptons A and C have equal and opposite sign y -charges, strict conservation of y -charge does not prevent generation of A and C excess, the excess of A being equal to excess of C . The mechanism of baryosynthesis in the present version of AC model is not clear, therefore the AC-lepton excess was postulated in [10, 12, 13] to saturate the modern CDM density (similar to the approach sinister model). Primordial excessive negatively charged A^{--} and positively charged C^{++} form a neutral most probable and stable (while being evanescent) (AC) "atom", the AC-gas of such "atoms" being a candidate for dark matter [10, 12, 13].

2.3 Stable pieces of 4th generation matter

Precision data on Standard model parameters admit [4] the existence of 4th generation, if 4th neutrino (N) has mass about 50 GeV, while masses of other 4th generation particles are close to their experimental lower limits, being $> 100\text{GeV}$ for charged lepton (E) and $> 300\text{GeV}$ for 4th generation U and D quarks [15]. The results of this analysis determine our choice for masses of N ($m_N = 50 \text{ GeV}$) and U ($m_U = 350S_5 \text{ GeV}$).

4th generation can follow from heterotic string phenomenology and

its difference from the three known light generations can be explained by a new gauge charge (y -charge), possessed only by its quarks and leptons [1, 3, 5]. Similar to electromagnetism this charge is the source of a long range Coulomb-like y -interaction. Strict conservation of y -charge makes the lightest particle of 4th family (4th neutrino N) absolutely stable, while the lightest quark must be sufficiently long living [3, 5]. The lifetime of U can exceed the age of the Universe, as it was revealed in [3, 5] for $m_U < m_D$.

The y -charges (Q_y) of (N, E, U, D) are fixed by the following conditions. Cancellation of $Z - \gamma - y$ anomaly implies $Q_{yE} + 2 \cdot Q_{yU} + Q_{yD} = 0$; while cancellation of $Z - y - y$ anomaly needs $Q_{yN}^2 - Q_{yE}^2 + 3 \cdot (Q_{yU}^2 - Q_{yD}^2) = 0$. Proper $N - E$ and $U - D$ transitions of weak interaction assume $Q_{yN} = Q_{yE}$ and $Q_{yU} = Q_{yD}$. From these conditions follows $Q_{yE} = Q_{yN} = -3 \cdot Q_{yU} = -3 \cdot Q_{yD}$ so that y -charges of (N, E, U, D) are $(1, 1, -1/3, -1/3)$.

U -quark can form lightest (Uud) baryon and $(U\bar{u})$ meson. The corresponding antiparticles are formed by \bar{U} with light quarks and antiquarks. Owing to large chromo-Coulomb binding energy ($\propto \alpha_c^2 \cdot m_U$, where α_c is the QCD constant) stable double and triple U bound states (UUq) , (UUU) and their antiparticles $(\bar{U}\bar{U}\bar{q})$, $(\bar{U}\bar{U}\bar{U})$ can exist [3, 8, 9]. Formation of these double and triple states in particle interactions at accelerators and in cosmic rays is strongly suppressed, but they can form in early Universe and strongly influence cosmological evolution of 4th generation hadrons. As shown in [5], anti- U -triple state called anutium or $\Delta_{3\bar{U}}^-$ is of special interest. This stable anti- Δ -isobar, composed of \bar{U} antiquarks and bound by chromo-Coulomb force has the size $r_\Delta \sim 1/(\alpha_{QCD} \cdot m_U)$, which is much less than normal hadronic size $r_h \sim 1/m_\pi$.

3 Grave shadows over the Sinister Universe

Glashow's sinister Universe was first inspiring example of composite dark matter scenario. The problem of such scenario is inevitable presence of "products of incomplete combustion" and the necessity to decrease their abundance. Indeed in analogy to D, ^3He and Li relics that are the intermediate catalyzers of ^4He formation in Standard Big Bang Nucleosynthesis (SBBN) and are important cosmological tracers of this process, the tera-lepton and tera-hadron relics from intermediate stages of a multi-step process of towards a final $(UUUEE)$ formation must survive with high abundance of *visible* relics in the present Universe. To avoid this trouble an original idea of (Ep) catalysis was proposed in

[8]: as soon as the temperature falls down below $T \sim I_{Ep}/25 \sim 1 \text{ keV}$ neutral (Ep) atom with "ionization potential" $I_{Ep} = \alpha^2 m_p/2 = 25 \text{ keV}$ can be formed. The hope was [8] that this "atom" must catalyze additional effective binding of various tera-particle species and to reduce their abundance below the experimental upper limits.

Unfortunately, as it was shown in [9], this fascinating picture of Sinister Universe can not be realized. Tracing in more details cosmological evolution of tera-matter and strictly following the conjecture of [8], the troubles of this approach were revealed and gracious exit from them for any model assuming -1 charge component of composite atom-like dark matter was found impossible.

The model [8] didn't offer any physical mechanism for generation of cosmological tera-baryon asymmetry and such asymmetry was postulated to saturate the observed dark matter density. This assumption was taken in [9] and it was revealed that while the assumed tera-baryon asymmetry for U washes out by annihilation primordial \bar{U} , the tera-lepton asymmetry of E^- can not effectively suppress the abundance of tera-positrons E^+ in the earliest as well as in the late Universe stages. This feature differs from successful annihilation of primordial antiprotons and positrons that takes place in our Standard baryon asymmetrical Universe. The abundance of \bar{U} and E^+ in earliest epochs exceeds the abundance of excessive U and E^- and it is suppressed (successfully) for \bar{U} only after QCD phase transition, while, there is no such effective annihilation mechanism for E^+ . Thus the tera-lepton pair overproduction was revealed as the first trouble of Sinister Universe.

Moreover ordinary ${}^4\text{He}$ formed in Standard Big Bang Nucleosynthesis binds at $T \sim 15 \text{ keV}$ virtually all the free E^- into positively charged $({}^4\text{He}E^-)^+$ "ion", which puts Coulomb barrier for any successive E^-E^+ annihilation or any effective EU binding. It happens *before* (Ep) atom can be formed and (Ep) atoms can not be formed, since all the free E are already imprisoned by ${}^4\text{He}$ cage. It removed the hope [8] on (Ep) atomic catalysis as *panacea* from unwanted tera-particle species and became the second unresolvable trouble for the Sinister Universe.

The huge frozen abundance of tera-leptons in hybrid tera-positronium (eE^+) and hybrid hydrogen-like tera-helium atom $({}^4\text{He}Ee)$ and in other complex anomalous isotopes can not be removed [9].

Their abundance is enormously high for known severe bounds on anomalous hydrogen. This is the grave nature of tera-lepton shadows

over a Sinister Universe.

The remaining abundance of (eE^+) and $({}^4HeE^-e)$ exceeds by *27 orders* of magnitude the terrestrial upper limit for anomalous hydrogen. There are also additional tera-hadronic anomalous relics, whose trace is constrained by the present data by *25.5 orders* for $(UUUEe)$ and *at least by 20 orders* for $(Uude)$ respect to anomalous hydrogen ($r < 10^{-30}$ relative to atom number density in Earth), as well as by *14.5 orders* for $(UUUee)$, by *10 orders* for $(UUuee)$ - respect to anomalous helium ($r < 10^{-19}$). While tera helium $(UUUEE)$ would co-exist with observational data, being a wonderful candidate for dark matter, its tera-lepton partners poison and forbid this opportunity.

The contradiction might be removed, if tera-fermions are unstable and drastically decay before the present time. But such solution excludes any cosmological sinister matter dominated Universe, while, of course, it leaves still room and challenge for search for metastable E -leptons and U -hadrons in laboratories or in High Energy Cosmic ray traces.

4 Composite dark matter from almost commutative geometry

Similar to the sinister Universe, AC-lepton relics from intermediate stages of a multi-step process towards a final (AC) atom formation must survive with high abundance of *visible* relics in the present Universe. In spite of the assumed excess of particles $(A^{--}$ and $C^{++})$ abundance of frozen out antiparticles $(\bar{A}^{++}$ and $\bar{C}^{--})$ is not negligible, as well as significant fraction of A^{--} and C^{++} remains unbound, when AC recombination takes place and most of AC-leptons form (AC) atoms. As soon as 4He is formed in Big Bang nucleosynthesis it captures all the free negatively charged heavy particles. If the charge of such particles is -1 (as it was the case for tera-electron in [8]) positively charged ion $({}^4He^{++}E^-)^+$ puts Coulomb barrier for any successive decrease of abundance of species, over-polluting by anomalous isotopes modern Universe. This problem of unavoidable over-abundance of by-products of "incomplete combustion" is avoided in AC-model owing to the double negative charge of A^{--} [12, 13]. Instead of positively charged ion the primordial component of free anion-like AC-leptons A^{--} are mostly trapped in the first three minutes into a puzzling neutral OLe-helium state (named so from *O-Lepton-helium*) $({}^4He^{++}A^{--})$, with nuclear interaction cross section, which provides anywhere eventual later (AC) binding. As soon as OLe-helium forms, it catalyzes in first three minutes effective binding in (AC) atoms and complete annihilation of antiparticles. Products

of annihilation cause undesirable effect neither in CMB spectrum, nor in light element abundances. Due to early decoupling from relativistic plasma γ -photon background is suppressed and its contribution to the total density in the period of Big Bang Nucleosynthesis is compatible with observational constraints. OLe-helium, this α particle with screened charge, can influence the chemical evolution of ordinary matter, but if OLe-helium interaction with nuclei is dominantly quasi-elastic and it might avoid over-production of anomalous isotopes (see below).

The development of gravitational instabilities of AC-atomic gas follows the general path of the CDM scenario, but the composite nature of (AC)-atoms leads to some specific difference. For $S_2 < 6$ the bulk of (AC) bound states appear in the Universe at $T_{fAC} = 0.7S_2 \text{ MeV}$ and the minimal mass of their gravitationally bound systems is given by the total mass of (AC) within the cosmological horizon in this period, which is of the order of $M = (T_{RM}/T_{fAC})m_{Pl}(m_{Pl}/T_{fAC})^2 \approx 6 \cdot 10^{33}/S_2^3 \text{ g}$, where $T_{RM} = 1 \text{ eV}$ corresponds to the beginning of the AC-matter dominated stage. At $S_2 > 6$ the bulk of (AC)-atoms is formed only at $T_{OHe} = 60 \text{ keV}$ due to OLe-helium catalysis. Therefore at $S_2 > 6$ the minimal mass is independent of S_2 and is given by $M = (T_{RM}/T_{OHe})m_{Pl}(m_{Pl}/T_{OHe})^2 \approx 10^{37} \text{ g}$.

At small energy transfer $\Delta E \ll m$ cross section for interaction of AC-atoms with matter is suppressed by the factor $\sim Z^2(\Delta E/m)^2$, being for scattering on nuclei with charge Z and atomic weight A of the order of $\sigma_{ACZ} \sim Z^2/\pi(\Delta E/m)^2\sigma_{AC} \sim Z^2A^210^{-43} \text{ cm}^2/S_2^2$. Here we take $\Delta E \sim 2Am_p v^2$ and $v/c \sim 10^{-3}$ and find that even for heavy nuclei with $Z \sim 100$ and $A \sim 200$ this cross section does not exceed $4 \cdot 10^{-35} \text{ cm}^2/S_2^2$. It proves WIMP-like behavior of AC-atoms in the ordinary matter. In the Galaxy they behave as collisionless gas.

Still, though CDM in the form of (AC) atoms is successfully formed, A^{--} (bound in OLe-helium) and C^{++} (forming anomalous helium atom (eeC^{++})) should be also present in the modern Universe and the abundance of primordial (eeC^{++}) is by up to *ten* orders of magnitude higher, than experimental upper limit on the anomalous helium abundance in terrestrial matter. This problem can be solved by OLe-helium catalyzed (AC) binding of (eeC^{++}), but different mobilities in matter of atomic interacting (eeC^{++}) and nuclear interacting (OHe) lead to fractionating of these species, preventing effective decrease of anomalous helium abundance. The $U(1)$ charge neutrality condition naturally prevents this fractionating, making (AC) binding sufficiently effective to suppress

terrestrial anomalous isotope abundance below the experimental upper limits. Inside dense matter objects (stars or planets) its recombination with (eeC^{++}) into (AC) atoms can provide a mechanism for the formation of dense (AC) objects. In this process OLe-helium and anomalous helium, which were coupled to the ordinary matter by hadronic and atomic interactions, convert into (AC) atoms, which immediately sinks down to the center of the body.

However, though (AC) binding is not accompanied by strong annihilation effects, as it was the case for 4th generation hadrons [3], gamma radiation from it inside large volume detectors should take place. In the course of (AC) atom formation electromagnetic transitions with $\Delta E > 1 \text{ MeV}$ can be a source of e^+e^- pairs, either directly with probability $\sim 10^{-2}$ or due to development of electromagnetic cascade. If AC recombination goes on homogeneously in Earth within the water-circulating surface layer of the depth $L \sim 4 \cdot 10^5 \text{ cm}$ inside the volume of Super Kamiokande with size $l_K \sim 3 \cdot 10^3 \text{ cm}$ equilibrium AC recombination should result in a flux of e^+e^- pairs $F_e = N_e I_C l_K / L$, which for $N_e \sim 1$ can be as large as $F_e \sim \cdot \frac{10^{-12}}{f(S_2)} \frac{S_b}{5 \cdot 10^{-5}} (cm^2 \cdot s \cdot ster)^{-1}$. Their signal might be easily disentangled [12, 13] (above a few MeV range) respect common charged current neutrino interactions and single electron tracks because the tens MeV gamma lead, by pair productions, to twin electron tracks, nearly aligned along their Cerenkov rings. The predicted signal strongly depends, however, on the uncertain astrophysical parameters [12, 13].

In this way AC-cosmology escapes most of the troubles, revealed for other cosmological scenarios with stable heavy charged particles [3, 9] and provides realistic scenario for composite dark matter in the form of evanescent atoms, composed by heavy stable electrically charged particles, bearing the source of invisible light.

5 Primordial composite forms of 4th generation matter

The model [3] admits that in the early Universe an antibaryon asymmetry for 4th generation quarks can be generated [5, 6]. Due to y -charge conservation \bar{U} excess should be compensated by \bar{N} excess. \bar{U} -antibaryon density can be expressed through the modern dark matter density $\Omega_{\bar{U}} = k \cdot \Omega_{CDM} = 0.224$ ($k \leq 1$), saturating it at $k = 1$. It is convenient [8, 9, 12, 5, 13, 6] to relate the baryon (corresponding to $\Omega_b = 0.044$) and \bar{U} (\bar{N}) excess with the entropy density s , introducing $r_b = n_b/s$ and $r_{\bar{U}} = n_{\bar{U}}/s = 3 \cdot n_{\bar{N}}/s = 3 \cdot r_{\bar{N}}$. One obtains

$r_b \sim 8 \cdot 10^{-11}$ and $r_{\bar{U}}$, corresponding to \bar{U} excess in the early Universe $\kappa_{\bar{U}} = r_{\bar{U}} - r_U = 3 \cdot (r_{\bar{N}} - r_N) = 10^{-12} (350 \text{ GeV}/m_U) = 10^{-12}/S_5$, where $S_5 = m_U/350 \text{ GeV}$. In the early Universe at temperatures highly above their masses \bar{U} and \bar{N} were in thermodynamical equilibrium with relativistic plasma. It means that at $T > m_U$ ($T > m_N$) the excessive \bar{U} (\bar{N}) were accompanied by $U\bar{U}$ ($N\bar{N}$) pairs.

Due to \bar{U} excess frozen out concentration of deficit U -quarks is suppressed at $T < m_U$ for $k > 0.04$ [6]. It decreases further exponentially first at $T \sim I_U \approx \bar{\alpha}^2 M_U/2 \sim 3S_5 \text{ GeV}$ (where [3] $\bar{\alpha} = C_F \alpha_c = 4/3 \cdot 0.144 \approx 0.19$ and $M_U = m_U/2$ is the reduced mass), when the frozen out U quarks begin to bind with antiquarks \bar{U} into charmonium-like state ($\bar{U}U$) and annihilate. On this line \bar{U} excess binds at $T < I_U$ by chromo-Coulomb forces dominantly into ($\bar{U}\bar{U}\bar{U}$) anutium states with electric charge $Z_\Delta = -2$ and mass $m_o = 1.05S_5 \text{ TeV}$, while remaining free \bar{U} anti-quarks and anti-diquarks ($\bar{U}\bar{U}$) form after QCD phase transition normal size hadrons ($\bar{U}u$) and ($\bar{U}\bar{U}\bar{u}$). Then at $T = T_{QCD} \approx 150 \text{ MeV}$ additional suppression of remaining U -quark hadrons takes place in their hadronic collisions with \bar{U} -hadrons, in which ($\bar{U}U$) states are formed and U -quarks successively annihilate.

Owing to weaker interaction effect of \bar{N} excess in the suppression of deficit N is less pronounced and it takes place at $T < m_N$ only for $k > 0.002$ [6]. At $T \sim I_{NN} = \alpha_y^2 M_N/4 \sim 15 \text{ MeV}$ (for $\alpha_y = 1/30$ and $M_N = 50 \text{ GeV}$) due to y -interaction the frozen out N begin to bind with \bar{N} into charmonium-like states ($\bar{N}N$) and annihilate. At $T < I_{NU} = \alpha_y^2 M_N/2 \sim 30 \text{ MeV}$ y -interaction causes binding of N with \bar{U} -hadrons (dominantly with anutium) but only at $T \sim I_{NU}/30 \text{ MeV}$ this binding is not prevented by back reaction of y -photo-destruction.

To the period of Standard Big Bang Nucleosynthesis (SBBN) \bar{U} are dominantly bound in anutium $\Delta_{3\bar{U}}^{--}$ with small fraction ($\sim 10^{-6}$) of neutral ($\bar{U}u$) and doubly charged ($\bar{U}\bar{U}\bar{u}$) hadron states. The dominant fraction of anutium is bound by y -interaction with \bar{N} in ($\bar{N}\Delta_{3\bar{U}}^{--}$) "atomic" state. Owing to early decoupling of y -photons from relativistic plasma presence of y -radiation background does not influence SBBN processes [3, 5].

At $T < I_o = Z^2 Z_{He}^2 \alpha^2 m_{He}/2 \approx 1.6 \text{ MeV}$ the reaction $\Delta_{3\bar{U}}^{--} + {}^4\text{He} \rightarrow \gamma + ({}^4\text{He}^{++} \Delta_{3\bar{U}}^{--})$ might take place, but it can go only after ${}^4\text{He}$ is formed in SBBN at $T < 100 \text{ keV}$ and is effective only at $T \leq T_{rHe} \sim I_o / \log(n_\gamma/n_{He}) \approx I_o/27 \approx 60 \text{ keV}$, when the inverse reaction of photo-

destruction cannot prevent it [9, 12, 5, 13]. In this period anutium is dominantly bound with \bar{N} . Since $r_{He} = 0.1r_b \gg r_\Delta = r_{\bar{U}}/3$, in this reaction all free negatively charged particles are bound with helium [9, 12, 5, 13] and neutral Anti-Neutrino-O-helium (ANO-helium, $ANOHe$) (${}^4He^{++}[\bar{N}\Delta_{3\bar{U}}^{--}]$) “molecule” is produced with mass $m_{OHe} \approx m_o \approx 1S_5\text{TeV}$. The size of this “molecule” is $R_o \sim 1/(Z_\Delta Z_{He}\alpha m_{He}) \approx 2 \cdot 10^{-13}$ cm and it can play the role of a dark matter component and a nontrivial catalyzing role in nuclear transformations.

In nuclear processes ANO-helium looks like an α particle with shielded electric charge. It can closely approach nuclei due to the absence of a Coulomb barrier and opens the way to form heavy nuclei in SBBN. This path of nuclear transformations involves the fraction of baryons not exceeding 10^{-7} [5] and it can not be excluded by observations.

5.1 ANO-helium catalyzed processes

As soon as ANO-helium is formed, it catalyzes annihilation of deficit U -hadrons and N . Charged U -hadrons penetrate neutral ANO-helium, expel 4He , bind with anutium and annihilate falling down the center of this bound system. The rate of this reaction is $\langle\sigma v\rangle = \pi R_o^2$ and an \bar{U} excess $k = 10^{-3}$ is sufficient to reduce the primordial abundance of (Uud) below the experimental upper limits. N capture rate is determined by the size of $(\bar{N}\Delta)$ “atom” in ANO-helium and its annihilation is less effective.

The size of ANO-helium is of the order of the size of 4He and for a nucleus A with electric charge $Z > 2$ the size of the Bohr orbit for a $(Z\Delta)$ ion is less than the size of nucleus A . This means that while binding with a heavy nucleus Δ penetrates it and effectively interacts with a part of the nucleus with a size less than the corresponding Bohr orbit. This size corresponds to the size of 4He , making O-helium the most bound $(Z\Delta)$ -atomic state.

The cross section for Δ interaction with hadrons is suppressed by factor $\sim (p_h/p_\Delta)^2 \sim (r_\Delta/r_h)^2 \approx 10^{-4}/S_5^2$, where p_h and p_Δ are quark transverse momenta in normal hadrons and in anutium, respectively. Therefore anutium component of $(ANOHe)$ can hardly be captured and bound with nucleus due to strong interaction. However, interaction of the 4He component of $(ANOHe)$ with a A_ZQ nucleus can lead to a nuclear transformation due to the reaction ${}^A_ZQ + (\Delta He) \rightarrow {}^{A+4}_{Z+2}Q + \Delta$, provided that the masses of the initial and final nuclei satisfy the energy condition $M(A, Z) + M(4, 2) - I_o > M(A + 4, Z + 2)$, where $I_o = 1.6\text{MeV}$ is the

binding energy of O-helium and $M(4, 2)$ is the mass of the ${}^4\text{He}$ nucleus. The final nucleus is formed in the excited $[\alpha, M(A, Z)]$ state, which can rapidly experience α -decay, giving rise to (*ANOHe*) regeneration and to effective quasi-elastic process of (*ANOHe*)-nucleus scattering. It leads to possible suppression of ANO-helium catalysis of nuclear transformations in matter.

5.2 ANO-helium dark matter

At $T < T_{od} \approx 1 \text{ keV}$ energy and momentum transfer from baryons to ANO-helium $n_b \langle \sigma v \rangle (m_p/m_o)t < 1$ is not effective. Here $\sigma \approx \sigma_o \sim \pi R_o^2 \approx 10^{-25} \text{ cm}^2$. and $v = \sqrt{2T/m_p}$ is baryon thermal velocity. Then ANO-helium gas decouples from plasma and radiation and plays the role of dark matter, which starts to dominate in the Universe at $T_{RM} = 1 \text{ eV}$.

The composite nature of ANO-helium makes it more close to warm dark matter. The total mass of (*OHe*) within the cosmological horizon in the period of decoupling is independent of S_5 and given by

$$M_{od} = \frac{T_{RM}}{T_{od}} m_{Pl} \left(\frac{m_{Pl}}{T_{od}} \right)^2 \approx 2 \cdot 10^{42} \text{ g} = 10^9 M_\odot.$$

O-helium is formed only at $T_o = 60 \text{ keV}$ and the total mass of *OHe* within cosmological horizon in the period of its creation is $M_o = M_{od}(T_o/T_{od})^3 = 10^{37} \text{ g}$. Though after decoupling Jeans mass in (*OHe*) gas falls down $M_J \sim 3 \cdot 10^{-14} M_{od}$ one should expect strong suppression of fluctuations on scales $M < M_o$ as well as adiabatic damping of sound waves in RD plasma for scales $M_o < M < M_{od}$. It provides suppression of small scale structure in the considered model. This dark matter plays dominant role in formation of large scale structure at $k > 1/2$.

The first evident consequence of the proposed scenario is the inevitable presence of ANO-helium in terrestrial matter, which is opaque for (*ANOHe*) and stores all its in-falling flux. If its interaction with matter is dominantly quasi-elastic, this flux sinks down the center of Earth. If ANO-helium regeneration is not effective and Δ remains bound with heavy nucleus Z , anomalous isotope of $Z - 2$ element appears. This is the serious problem for the considered model.

Even at $k = 1$ ANO-helium gives rise to less than 0.1 [5, 6] of expected background events in XQC experiment [16], thus avoiding for all $k \leq 1$ severe constraints on Strongly Interacting Massive particles SIMPs obtained in [17] from the results of this experiment. In underground detectors (*ANOHe*) “molecules” are slowed down to thermal

energies far below the threshold for direct dark matter detection. However, (*ANOHe*) destruction can result in observable effects. Therefore a special strategy in search for this form of dark matter is needed. An interesting possibility offers development of superfluid ${}^3\text{He}$ detector [18]. Due to high sensitivity to energy release above ($E_{th} = 1\text{ keV}$), operation of its actual few gram prototype can put severe constraints on a wide range of k and S_5 [19].

At $10^{-3} < k < 0.02$ U -baryon abundance is strongly suppressed [6], while the modest suppression of primordial N abundance does not exclude explanation of DAMA, HEAT and EGRET data in the framework of hypothesis of 4th neutrinos [1] but makes the effect of N annihilation in Earth consistent with the experimental data.

6 Discussion

To conclude, the existence of heavy stable charged particles can offer new solution for dark matter problem. Dark matter candidates can be atom-like states, in which negatively and positively stable charged particles are bound by Coulomb attraction. Primordial excess of these particles over their antiparticles implies the mechanism of its generation and is still an open problem for all the considered models. However, even if such mechanism exists, there is a serious problem of accompanying anomalous forms of atomic matter.

Indeed, recombination of charged species is never complete in the expanding Universe, and significant fraction of free charged particles should remain unbound. Free positively charged species behave as nuclei of anomalous isotopes, giving rise to a danger of their over-production. Moreover, as soon as ${}^4\text{He}$ is formed in Big Bang nucleosynthesis it captures all the free negatively charged heavy particles. If the charge of such particles is -1 (as it is the case for tera-electron in [8]) positively charged ion (${}^4\text{He}^{++}E^{-})^{+}$ puts Coulomb barrier for any successive decrease of abundance of species, over-polluting modern Universe by anomalous isotopes. It excludes the possibility of composite dark matter with -1 charged constituents and only -2 charged constituents avoid these troubles, being trapped by helium in neutral OLe-helium or O-helium (ANO-helium) states.

The existence of -2 charged states and the absence of stable -1 charged constituents can take place in AC-model and in charge asymmetric model of 4th generation. In the first case, pregalactic abundance of C^{++} exceeds by ten orders of magnitude the terrestrial upper limit on

anomalous helium and the mechanism of suppression of this abundance is inevitably accompanied by observable effects of recombination and implies the existence of y charge, possessed by AC leptons. In the second case, owing to excess of \bar{U} anti-quarks primordial abundance of positively charged U -baryons is exponentially suppressed and anomalous isotope over-production is avoided. Excessive anti- U -quarks should retain dominantly in the form of anutium, which binds with excessive \bar{N} and then with 4He in neutral ANO-helium. In the both cases, OLe-helium (or ANO-helium) should exist and its possible role in nuclear transformation is the serious danger (or exciting advantage?) for composite dark matter scenario.

Galactic cosmic rays destroy ANO-helium (as well as OLe-helium), striking off 4He . It can lead to appearance of a free [anutium- \bar{N}] component in cosmic rays, which can be as large as $[\bar{N}\Delta_{3\bar{U}}^{--}]/{}^4He \sim 10^{-7}$ and accessible to PAMELA and AMS experiments. The estimation is two orders less in the case of free A^{--} from cosmic ray destruction of OLe-helium [13].

In the context of composite dark matter like [5, 6] or [12, 13] accelerator search for new stable quarks and leptons acquires the meaning of critical test for existence of its charged components. Such test will be possible in experiment ATLAS/LHC [6, 7].

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